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NUCLEAR WINTER SOURCE-TERM STUDIES

Volume II—The Classification of U.S. Cities

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14 August 1987

Technical Report

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A theory for classifying U.S. cities according to their burnable densities is developed. Urban land use, which is closely related to combustible loadings, is shown to be a classification correlate superior to the conventional measures of city rank such as population, urban area, or population density. Six classes of cities are defined. The basic division is regional and the classification is shown to account for the demographic and economic characteristics that distinguish U.S. urban areas. Estimates of smoke production based on analysis of sample cities from each group would systematically account for differences in urban geographies.

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PREFACE

This effort is a continuation of the Pacific-Sierra Research Corporation (PSR) study of the global effects of a nuclear exchange. In this report, a classification theory for grouping similar cities is developed. Estimates of smoke production from urban areas could thus account for differences in U.S. cities. The classification scheme is one part of our urban area smoke production analysis. Other volumes in this series describe the structure of U.S. cities, collocation of target and urban areas, fuel loadings, and an estimate of smoke produced by a nuclear strike against the United States.

CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI) units of measurement

MULTIPLY → BY → TO GET
TO GET ← BY ← DIVIDE

angstrom	1.000 000 X E -10	meters (m)
atmosphere (normal)	1 013 25 X E +2	kilo pascal (kPa)
bar	1 000 000 X E +2	kilo pascal (kPa)
barn	1 000 000 X E -28	meter^2 (m^2)
British thermal unit (thermochemical)	1 054 350 X E +3	joule (J)
calorie (thermochemical)	4 184 000	joule (J)
cal (thermochemical)/cm^2	4 184 000 X E -2	mega joule/m^2 (MJ/m^2)
curie	3 700 000 X E +1	*giga becquerel (GBq)
degree (angle)	1 745 329 X E -2	radian (rad)
degree Fahrenheit	$t_K = (t°f + 459.67)/1.8$	degree kelvin (K)
electron volt	1 602 19 X E -19	joule (J)
erg	1.000 000 X E -7	joule (J)
erg/second	1.000 000 X E -7	watt (W)
foot	3 048 000 X E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U S liquid)	3 785 412 X E -3	meter^3 (m^3)
inch	2 540 000 X E -2	meter (m)
jerk	1 000 000 X E +9	joule (J)
joule/kilogram (J/kg) (radiation dose absorbed)	1.000 000	Gray (Gy)
kilotons	4 183	terajoules
kip (1000 lbf)	4 448 222 X E +3	newton (N)
kip/inch^2 (ksi)	6 894 757 X E +3	kilo pascal (kPa)
ktap	1 000 000 X E +2	newton-second/m^2 (N-s/m^2)
micron	1 000 000 X E -6	meter (m)
mil	2 540 000 X E -5	meter (m)
mile (international)	1.609 344 X E +3	meter (m)
ounce	2 834 952 X E -2	kilogram (kg)
pound-force (lbs avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 X E -1	newton-meter (N·m)
pound-force/inch	1 751 268 X E +2	newton/meter (N/m)
pound-force/foot^2	4 788 026 X E -2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6 894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4 535 924 X E -1	kilogram (kg)
pound-mass-foot^2 (moment of inertia)	4 214 011 X E -2	kilogram-meter^2 (kg·m^2)
pound-mass/foot^3	1 601 846 X E +1	kilogram/meter^3 (kg/m^3)
rad (radiation dose absorbed)	1 000 000 X E -2	**Gray (Gy)
roentgen	2 579 760 X E -4	coulomb/kilogram (C/kg)
shake	1 000 000 X E -8	second (s)
slug	1 459 390 X E +1	kilogram (kg)
torr (mm Hg, 0° C)	1 333 22 X E -1	kilo pascal (kPa)

*The becquerel (Bq) is the SI unit of radioactivity, 1 Bq = 1 event/s
**The Gray (Gy) is the SI unit of absorbed radiation

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SECTION 1
INTRODUCTION

Several hundred thousand square kilometers of urban and nonurban land could be burned as a result of a nuclear exchange between the superpowers. The nonurban areas would produce only a minimal amount of smoke [Small and Bush, 1985]--far less than the cities [Turco et al., 1987]. Wildland fuel loadings are, in general, small (usually less than 1 g/cm^2) and fire starts are strongly dependent on fuel moisture and weather. That is not so for the urban areas where fuel loads can be 1 to 2 orders of magnitude greater. The combustibles in cities are essentially dry, and weather is not a primary variable. The composition of a city (size, land use, building densities. transportation arteries, open areas, etc.) is, however, important.

Not all cities are alike. A generic model of a city's structure or building distribution is not likely to be an accurate representation of all U.S., European, and Soviet cities. Similarly, a single real city is probably a poor model for the set of all U.S. cities (Los Angeles is quite unlike Baltimore; Seattle is different from Nashville; etc.). Yet, some cities are seemingly similar. Such cities could be grouped, providing a technical basis for similarity is identified.

Several measures of urban areas describe rank, but do not distinguish urban geographies. City area, population, and population density are such measures. Although each is relevant in describing an urban area, fuel loadings and probable fire vulnerabilities are not easily derived from such parameters. The functional role [Smailes, 1955]. socioeconomic factors, geographical location, topography, climate, and age of a city may be more relevant parameters.

Zonal [Burgess, 1929] or sector [Hoyt, 1964] city models are first-order descriptions of city structure based on function and socioeconomic factors. In each model, a city is divided into geographic sections according to general function or usage. Not all cities, however, could be described by either of those models.

Nevertheless, a formalized method for estimating combustible loadings is suggested.

The first nuclear winter studies [Crutzen and Birks 1982; Turco et al., 1983; and Crutzen, Galbally, and Bruhl, 1984] used either a zonal city model or industrial production statistics to estimate the amount of combustible material in Northern Hemisphere urban areas. The zonal model recognizes different land uses and fuel densities in a crude manner, but is probably not representative of any particular contemporary U.S. city [Scargill, 1979] or group of cities. Fuel loadings based on production statistics neglect city geography completely and rely on either the urban population or the number of buildings. Crutzen, Galbally, and Bruhl, [1984] compared estimates and found substantial (≈ 250 percent) differences.

The distribution of combustibles in an urban area determines nearly all the important fire parameters such as burning intensity, fire duration, spread, and smoke production. Other factors such as scenario, specific emission factors, target location, etc., are also important, but can be established independent of the urban geography. The distribution of combustibles (fuel loading), however, is closely related to the city structure. High building density city areas could support intense, long-burning fires; low building density or open areas may support only weak fires. Each city could be different.

In this report, we identify characteristics of urban areas that influence fire behavior, and develop correlations that distinguish groups of cities. The classification of individual cities is based on land use (residential, commerical, industrial, etc.), which is closely related to combustible densities. U.S. cities are divided into six classes. Estimates of smoke production based on analysis of one or more cities from each class systematically account for differences in urban geographies. Such estimates are presented in Vol. 6 of this report series. In this volume, the classification theory is developed.

SECTION 2
CITY CLASSIFICATION

A single generic model of city geography would be a poor basis for calculating fire behavior and estimating smoke production for all Northern Hemisphere cities unless it is demonstrated that the model represents the mean characteristics of a group of cities. That has not been done. Thus, even though a particular model may well approximate building or fuel-loading distribution in a designated city, if used to represent all urban areas, it may significantly overestimate or underestimate the amount and density of combustibles. The estimate of smoke production would be at least as uncertain as the fuel estimate.

Urban areas are not generally classified or grouped by combustible distributions. Although there are a number of variables that identify fuel loading differences in cities, those that distinguish groups of cities or are proper correlates are not readily apparent. Clearly, however, even a simple classification theory can account for differences between cities. For example, a more precise smoke estimate could be made by classifying cities as either industrial or nonindustrial. The fuel loadings differ for the two, and if the industrial cities are more heavily targeted, the smoke production would be greater. Even this simple two-category classification more appropriately weights scenario and industrial/nonindustrial city characteristics than a single generic model.

In the above example, function was the specific correlate, and we assumed that there was a corresponding structural difference in the two types of urban geography. In general, cities with concentrations of industry have greater-than-average fuel loadings, but even within this single class there may be wide variations. The older manufacturing cities in the East and Midwest may, for example, be more dense than the relatively newer cities of the West. A classification system with more than two categories is needed.

Function (i.e., industrial, commercial) implies density, but a single category is evidently not sufficient to group cities, because several elements combine to define city structure. Transportation arteries, topography, age, and economic functions (dominant industries, commerce, per capita income, etc.) influence city development and use of the land. Manufacturing, or industry, is one type of land use. Others include housing, commercial areas, streets, parks, cemetaries, golf courses, and open areas. Each of these types of land use can be assigned a fuel or combustible loading value; correlation of multiple variables is required.

While it is clear that fuel loading relates to land use, there is no apparent correlation of urban land use with the economic, demographic, and geographic parameters that could be used to distinguish classes or groups of cities. There are, however, several data sets that identify observable characteristics of U.S. urban areas. Demographic and economic data have been compiled by the Bureau of the Census [Goldfield, 1967] and data on urban land use by Manvel* [1968]. In the following analysis, regressions are developed to identify the statistically significant city descriptors related to fuel loading. Natural groupings are indicated by the deviation of individual cities from the regressions. Cities in the same group show similar magnitude deviations. The groupings suggested by the variations apparent in the regressions are further developed through an analysis of variance of the land use categories.

Several land use classification systems have been developed. Since end users range from local and regional political agencies to private organizations there is no unique categorization. Three classifications are shown in Table 1. In each, residential, commercial, and industrial areas are distinguished. The six- and eight-class schemes [Manvel, 1968] further identify single- and multiple-family residential use; the Land Use for Developed Area (LUDA) scheme [Ander-

*Manvel's compilation is based on a survey of 106 cities with populations greater than 100,000 people. The sample, although extensive, is weighted somewhat toward the larger cities (there are 173 census places with population greater than 100,000 and 965 cities with population between 25,000 and 100,000).

Table 1. Three urban land use classifications.

Six-Class[a]	Eight-Class[a]	LUDA[b]
Single-family residential	Single-family residential	11. Residential
Multiple-family residential	Multiple-family residential	12. Commercial, services
Commercial	Commercial	13. Industrial
Industrial	Industrial	14. Transportation, communication, utilities
Streets	Transportation	15. Industrial and commercial complexes
Public, semipublic	Education	16. Mixed urban
	Streets	17. Other urban
	Public, semipublic	

[a]Manuel [1968].

[a]Anderson et al. [1976]; numbers refer to U.S. Geological Survey categories.

son et al., 1976] defines two categories of mixed usage. The eight-class breakdown includes categories for educational facilities and transportation. (Educational facilities are considered commercial in the other classifications.) The LUDA scheme classifies public or semipublic (parks, cemetaries, golf courses, etc.) areas as either commercial or other. Street area is not a LUDA category. Each classification describes major urban divisions that could correlate with combustible loadings. Statistics for the six-class groupings are presented in the main body of this report; results based on the eight-class and LUDA breakdowns are presented in the appendix.

The correlation coefficients* listed in Table 2 (and in the appendix) indicate the directness of the relationship between demographic and economic parameters and the types of land use for each classification scheme shown in Table 1. The coefficients identify the principal urban descriptors. For example, measures of rank such as population or unincorporated area correlate poorly ($r = 0.5$) with land use. The number of families, however, shows a strong correlation ($r = 0.9$) with most categories of urban land use. Similarly, employment, the number of housing units, and to a lesser extent, the total urban or developed area correlate well with the land use classes.

Although population is apparently a poor correlate, deviations from the regression curves suggest that within a population group, the correlations might improve. Large metropolitan areas, for example, may be similar; cities with population (say) between 100,000 to 250,000 may be alike. The regressions also seem to indicate a geographic bias or grouping of cities by region, roughly consistent with variations in economic activity. The first uses a type of rank as a correlate; the second uses location. To test the first hypothesis, four population classes are defined. Although the correlations were weak, some trends were apparent. The fraction of built-up area devoted to single-family residences showed no sig-

*For the correlation coefficient r, the quantity $1 - r^2$ represents the fraction of the error in one regression variable that can be attributed to errors in the other. Thus, values of r near 1 indicate strong correlation, and those near zero imply weak correlation.

Table 2. Correlation coefficients for six-class breakdown versus census data.

Census Data	Six-Class Area Breakdown					
	Single-Family	Multiple-Family	Commercial	Industrial	Street	Public
Incorporated area	0.72	0.45	0.59	0.63	0.65	0.66
Urban area[a]	0.99	0.90	0.92	0.87	0.95	0.55
Population	0.43	0.64	0.73	0.60	0.86	0.59
Families	0.91	0.91	0.83	0.83	0.90	0.20
Housing units	0.89	0.90	0.80	0.80	0.87	0.17
Employment	0.91	0.91	0.83	0.82	0.89	0.20
Retail firms			0.83			
Retail employment			0.84			
Wholesale firms			0.84			
Wholesale employment			0.85			
Service firms			0.82			
Service employment			0.83			
Commercial firms			0.84			
Commercial employment			0.85			
Manufacturing firms				0.76		
Manufacturing employment				0.73		
Production workers				0.74		
City government employment						0.24
Multiple-family units		0.79				

[a]Equal to sum of land areas for the six classes.

nificant variation, but the area devoted to multiple-family residences decreased with size for each class. Surprisingly, the industrialized fraction of urban areas varied inversely with the population classes. The geographic pattern apparent in the regressions suggested that both time and region of settlement during the growth of the U.S. strongly influenced the land use characteristics of cities. Age is thus a likely correlate.

The century in which a major city was founded [Northam, 1975] turns out to be a markedly better method (than population rank) of categorizing cities. It accounts for the age of a city and roughly indicates a geographic bias similar to that observed in the regressions of demographic and land use data. Figure 1 shows the regions of development by century of foundation for U.S. cities (in the contiguous 48 states) with populations over 100,000 in 1970. Early development was mainly in the coastal areas. Cities in inland areas developed first along the major rivers, then along rail lines, and finally along major highways.

The differences in land use based on the century in which a city was founded are shown in Fig. 2. Large changes in fractional land area are indicated for multiple-family housing (Fig. 2b) and industry (Fig. 2d), although the largest statistically significant changes (based on an analysis of variance) are in the fractional land area used for single-family housing (Fig. 2a) and streets (Fig. 2e). The importance of city age is demonstrated in Fig. 3. Newer cities have developed somewhat less than half their incorporated areas; older cities, particularly those formed in the seventeenth and eighteenth centuries utilize most of their incorporated areas. This implies higher densities in the older cities.

In distinguishing city structure or land use by century of foundation, a regional similarity in groups of cities is apparent (cf. Figs. 1 and 2). The resolution is limited, however, since century rather than a geographical parameter is the principal correlate. Nevertheless, the basis for a more precise division is established. Using economic data [Goldfield, 1967; Bureau of the Census, 1983]

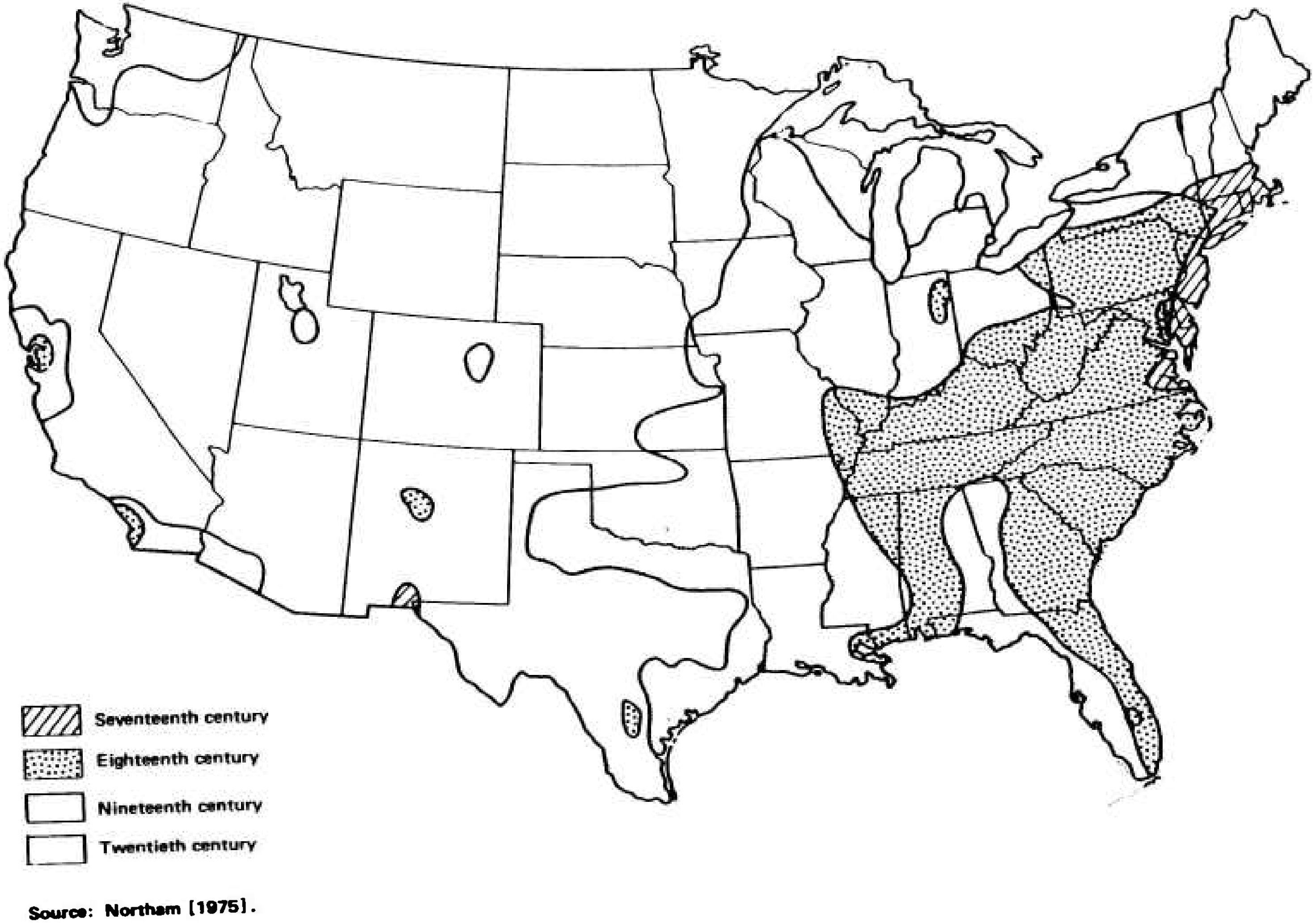
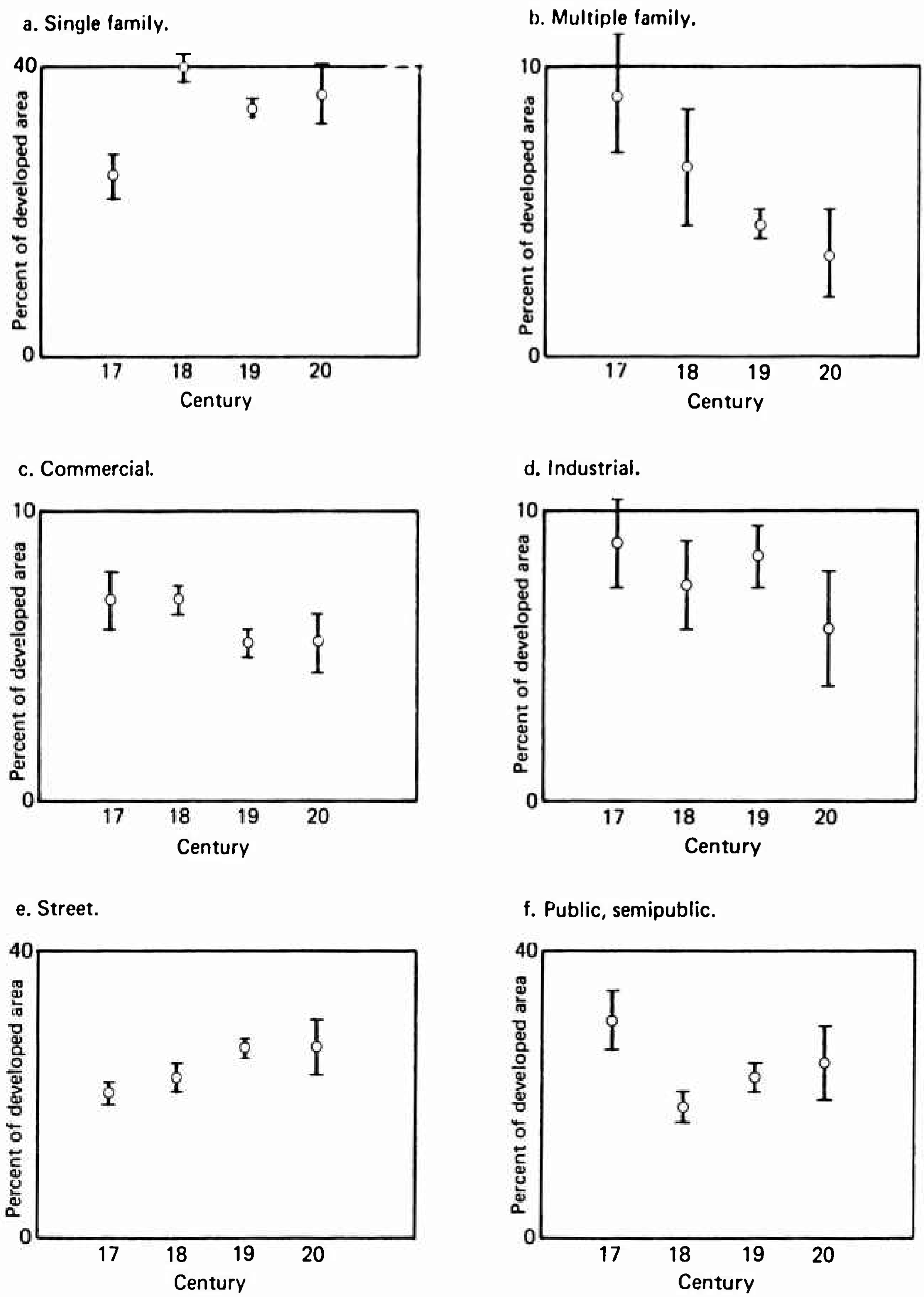
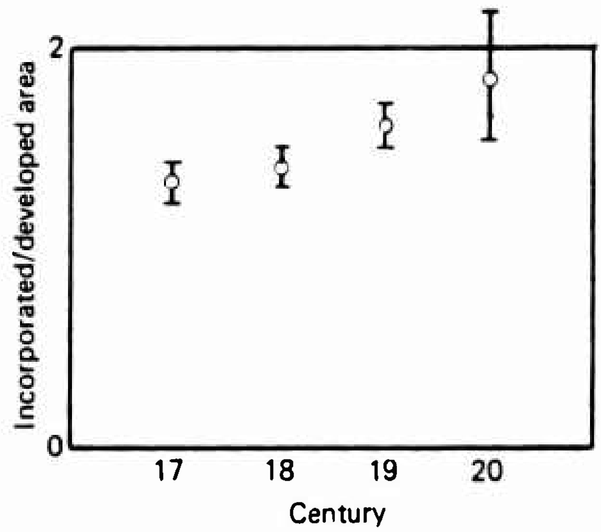


Figure 1. Century of foundation for U.S. cities in contiguous 48 states.



Note: Error bars represent one standard deviation.

Figure 2. Land use fractional areas for cities founded in different centuries.



Note: Error bars represent one standard deviation.

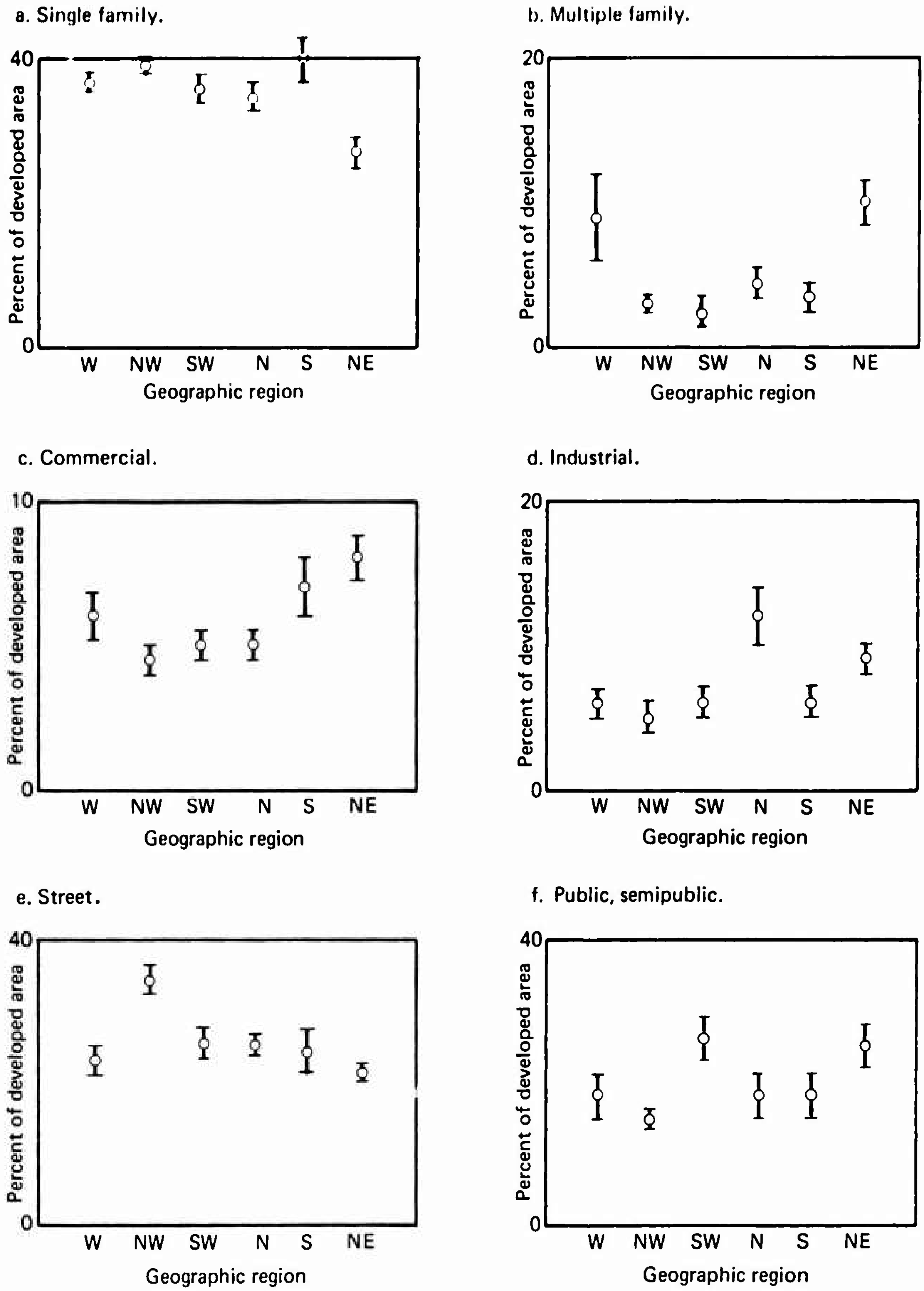
Figure 3. Ratio of incorporated to developed or built-up area as function of age.

in combination with Fig. 1, a more natural regional breakdown is apparent.

State boundaries are obvious region dividers, yet city groups developed using such demarcations do not exhibit significant variation in the land use classes; the groupings are not statistically distinct. Adding or deleting states from the regions does not greatly improve the distinction indicated by the century of foundation classification. The political (state) lines are somewhat arbitrary and do not necessarily reflect demographic and economic trends such as the location and size of different industrial centers and the development of cities along transportation arteries.

Beginning with the basic separation indicated by the century of foundation categorization and demographic data, regional boundaries were developed such that distinguished sets or groups of cities were formed. Some divisions are natural--on the West Coast, cities in Northern California are more similar to those in the Pacific Northwest than to those in Southern California, which forms a separate and distinct region. Although it is the smallest of the six geographical regions, it contains the major economic concentrations and population centers of the western U.S. The boundary between the region containing the industrial centers in the Midwest and Ohio Valley (northern group) and the cities of the northeastern corridor splits Pennsylvania and Virginia; Pittsburgh is in the northern group, Philadelphia in the northeastern group. Such division more properly recognizes economic roles and thus a city's fuel-loading characteristics than a political boundary. The southern regional boundary splits Missouri, Kentucky, Virginia, and West Virginia in the north and Arkansas and a small part of Texas in the west. The southwestern region extends to California in the west and splits Idaho, Wyoming, and Nebraska in the north.

The six-class land use breakdown applied to each of the geographic regions is shown in Fig. 4. In the appendix, similar results are shown for the LUDA and eight-class breakdowns. The region boundaries are shown in Fig. 5. With the exception of public and semipublic land use, there are significant regional differences in all land use categories. Land use distinctions between the regions, but



Note: Error bars represent one standard deviation.

Figure 4. Land use fractional areas for cities in classification groups (six land use classes).

similarity within the regions, implies values for combustible densities unique to each group of cities.

Cities in the Northeast (NE) have a noticeably smaller fraction of developed area devoted to single-family housing, and a larger than average fraction devoted to multiple-family housing. This implies higher than average population and building densities; such trends are consistent with the age and development period of those cities.

Both the Northeast and West (W) have multiple-family proportions more than a factor of 2 greater than other regional averages. The Northeast, South (S) and West show similarities in commercial land use. Also notable is the intense industrial land use in the North (N) (see Fig. 4d). Much of the U.S. industrial capacity is in that region, and the cities have higher than average numbers of factories or industrial floor space. Such differences influence the fuel loadings. There is a high land use fraction dedicated to streets in the Northwest (NW) (see Fig. 4e); use in this category is nearly constant across the other regions.

Similar statistics were developed for the eight-class and LUDA land use breakdowns (shown in the appendix). The trends apparent in the six-class scheme are repeated in the eight-class breakdown, with the exception of the amount of developed area devoted to transportation facilities. Significant differences between the West and Northwest and the other regions are obtained for this land use. Regional differences are less pronounced in the LUDA categorization, which uses a single classification of residential land use rather than dividing that usage into high (multiple-family) and low (single-family) density categories. The use of mixed categories (LUDA 16 and LUDA 17) smooth the differences in variance apparent with six- and eight-class land use breakdowns. An analysis based on per capita land area rather than land use is also presented in the appendix. The results show that the classification based on land use better represents economic function and city characteristics than a per capita analysis.

Table 3 summarizes the mean values for each of the six-class land use categories by geographic region (see Fig. 5). Although each group

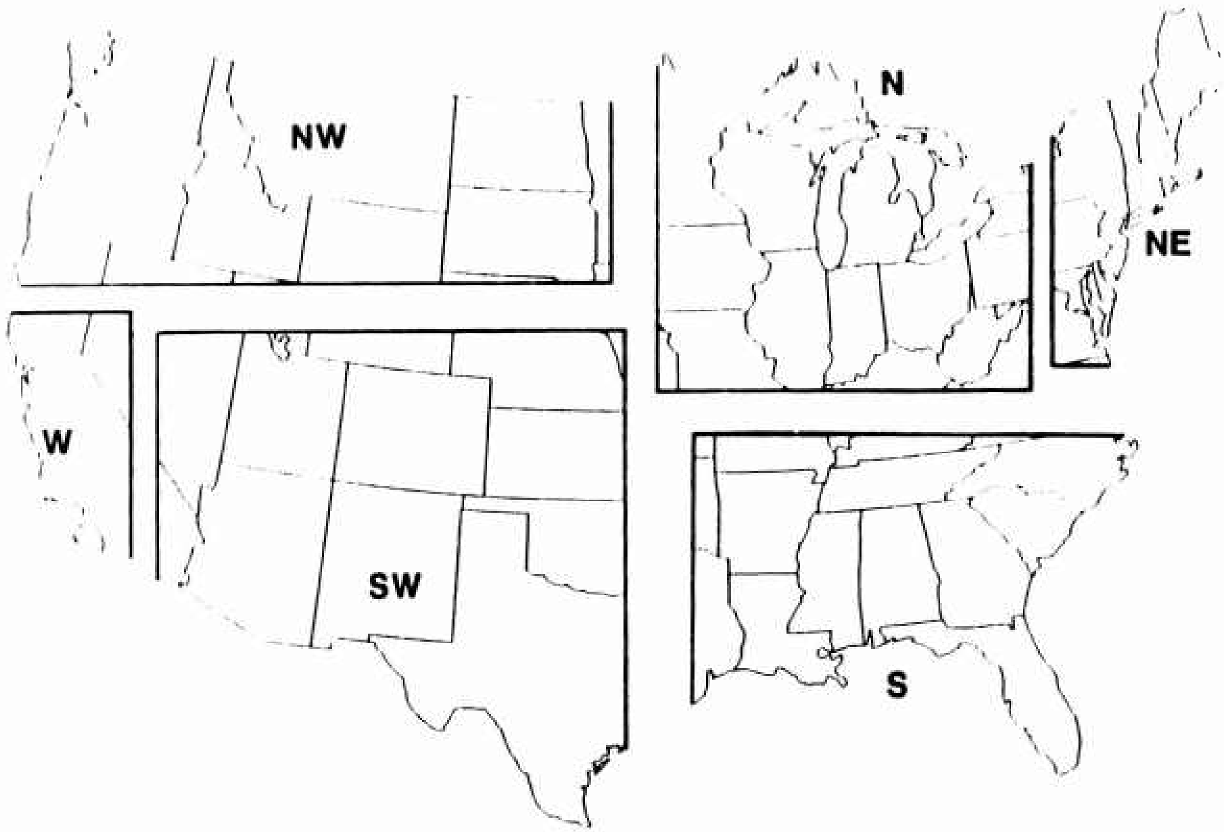


Figure 5. Regional classification of U.S. cities (contiguous 48 states).

Table 3. Mean values of land use for six-class breakdown by region.

Use Category, Per Developed Area	Geographic Region (mean value in percent) W	NW	SW	N	S	NE
Single-family area	37.4	38.9	35.6	35.0	40.3	26.4
Multiple-family area	9.25	2.69	2.71	4.74	3.66	10.01
Commercial area	6.08	4.73	5.17	5.17	7.09	7.87
Industrial area	5.93	4.80	6.09	12.00	5.92	9.14
Street area	22.9	33.8	24.7	25.0	24.0	21.2
Semipublic area	18.4	15.1	25.7	18.1	19.0	25.3

is distinct, there are relatively small deviations from the grand mean in several of the categories. This reflects the relative homogeneity in the U.S. standard of living. There are, however, statistically significant differences in the fraction of multiple-family and industrial land use. This implies variation in combustible densities [Small et al., 1987, Anno et al., 1987].

Finally, correlation coefficients were calculated for each land use category against the demographic and economic parameters used in Table 2. Separate regressions were performed for each region. The results (listed in Table 4) show significant improvement in the correlations for most parameters. The regression of single-family area and population shown in Table 4 is typical. For the country as a whole, the correlation is rather weak ($r = 0.43$), but when the country is divided into geographic regions (in Fig. 5) most coefficients are around 0.9. The classification of U.S. cities by region using land use as a correlate indicative of fuel loading thus seems consistent with most measures of city characteristics.

Table 4. Regression coefficients for six-class area breakdown.

Correlate	W	NW	SW	N	S	NE	All
	Geographic Region						
Single-Family Area							
Incorporated area	0.90	0.98	0.96	0.88	0.73	0.96	0.76
Developed area	1.00	1.00	0.98	0.86	0.96	0.88	0.99
Population	0.98	1.00	0.99	0.85	0.69	0.92	0.43
Families	1.00	1.00	0.95	0.71	0.52	0.30	0.92
Housing units	0.97	1.00	0.94	0.73	0.41	0.29	0.90
Single-family units	0.99	1.00	0.97	0.81	0.74	0.88	0.97
Employment	1.00	1.00	0.95	0.73	0.55	0.22	0.92
Multiple-Family Area							
Incorporated area	0.82	0.98	0.08	0.81	0.45	0.13	0.51
Developed area	1.00	1.00	0.77	0.92	0.93	0.67	0.90
Population	0.98	1.00	0.20	0.85	0.25	0.50	0.64
Families	1.00	1.00	0.83	0.83	0.46	0.84	0.91
Housing units	0.96	1.00	0.84	0.81	0.36	0.84	0.90
Multiple-family units	0.88	1.00	0.71	0.73	-.01	0.74	0.79
Employment	1.00	1.00	0.81	0.82	0.49	0.78	0.91
Commercial Area							
Incorporated area	0.89	0.99	0.89	0.91	0.50	0.89	0.66
Developed area	1.00	1.00	0.93	0.73	0.91	0.87	0.92
Population	0.97	1.00	0.91	0.93	0.54	0.93	0.73
Families	0.99	1.00	0.90	0.55	0.46	0.49	0.83
Housing units	0.95	1.00	0.88	0.56	0.39	0.48	0.80
Employment	0.99	1.00	0.91	0.56	0.48	0.38	0.83
Retail firms	0.99	1.00	0.92	0.53	0.42	0.64	0.83
Retail employment	0.99	1.00	0.91	0.59	0.46	0.71	0.84
Wholesale firms	0.99	1.00	0.91	0.63	0.45	0.28	0.84
Wholesale employment	0.99	1.00	0.92	0.61	0.60	0.23	0.85
Service firms	0.99	1.00	0.87	0.60	0.31	0.36	0.82
Service employment	0.99	1.00	0.91	0.58	0.28	0.21	0.83
Commercial firms	0.99	1.00	0.91	0.58	0.39	0.54	0.84
Commercial employment	0.99	1.00	0.92	0.60	0.47	0.53	0.85

Table 4. Regression coefficients for six-class area breakdown (Concluded).

Correlate	Geographic Region W	NW	SW	N	S	NE	All
Industrial Area							
Incorporated area	0.91	0.88	0.74	0.70	0.52	0.88	0.70
Developed area	0.99	0.79	0.81	0.46	0.78	0.86	0.87
Population	0.93	0.80	0.79	0.67	0.91	0.82	0.60
Families	0.98	0.79	0.88	0.33	0.87	0.51	0.83
Housing units	0.97	0.78	0.88	0.31	0.80	0.52	0.81
Employment	0.98	0.79	0.85	0.32	0.84	0.41	0.82
Manufacturing firms	0.98	0.87	0.82	0.26	0.45	0.16	0.77
Manufacturing employment	0.97	0.87	0.78	0.36	0.88	0.31	0.74
Production workers	0.98	0.89	0.80	0.35	0.87	0.32	0.75
Street Area							
Incorporated area	0.99	0.99	0.94	0.96	0.83	0.98	0.73
Developed area	0.99	1.00	0.97	0.93	0.73	0.92	0.95
Population	0.97	1.00	0.98	0.96	0.84	1.00	0.86
Families	0.98	1.00	0.94	0.86	0.96	0.75	0.90
Housing units	0.96	1.00	0.93	0.87	0.92	0.74	0.87
Employment	0.98	1.00	0.95	0.87	0.94	0.66	0.89
Semipublic Area							
Incorporated area	0.62	0.96	0.90	0.85	0.14	1.00	0.54
Developed area	0.79	0.99	0.89	0.59	0.95	0.83	0.55
Population	0.27	0.99	0.80	0.81	0.62	0.99	0.73
Families	0.79	0.99	0.77	0.34	0.47	0.49	0.37
Housing units	0.82	0.99	0.74	0.35	0.37	0.49	0.33
Employment	0.79	0.99	0.72	0.34	0.46	0.43	0.35
City government employment	0.77	0.95	0.61	0.38	0.87	0.63	0.38
Sum of Developed Land Use Areas							
Incorporated area	0.99	0.99	0.94	0.97	0.85	0.99	0.94

SECTION 3
CONCLUSIONS

We have demonstrated that large (population ≥100,000) U.S. cities most naturally fall into six geographic categories when classified according to developed-area land use. The classification recognizes and accounts for the demographic and economic patterns that distinguish urban areas. Since land use is the principal correlate and is directly related to building distributions, each group of cities has a distinctive combustible mix and loading. Densities vary significantly--as much as 250 percent--between the city groups. Based on the city classification scheme, estimates of smoke production can be obtained that systematically account for differences in urban geography.

SECTION 4

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APPENDIX

STATISTICS BASED ON EIGHT-CLASS AND LUDA LAND USE CATEGORIES

The results presented in Sec. 2 were developed from calculations based on the six-category land use breakdown. Statistics were also developed for eight-class and LUDA land use breakdowns. The six-class breakdown provided the most relevant information. Correlations of demographic data with the eight-class and LUDA categories are presented in Tables 5 and 6. The results of analyses by geographic region are shown in Figs. 6 and 7. Regression coefficients by region are given for both land use breakdowns in Tables 7 and 8.

An alternative analysis based on per capita land area rather than land use as a fraction of developed area was explored since land use should in principle correlate with population. Although population rank (see Table 2) was in general a poor correlate (see p. 6), it proved to be a better correlate for comparisons within each of the six regions. The results are presented in Fig. 8. The difference in population density among cities in the same region caused the variance within each land use category to be large--much larger than shown in Fig. 5. Fractional land use, which is related to function or principal economic activity, more properly classifies city characteristics than per capita land use. This is consistent with Table 1.

Table 5. Correlation coefficients for eight-class area versus census data.

Census Data	Eight-Class Area							
	Single-Family	Multiple-Family	Commmerical	Industrial	Tranportation	Education	Street	Public
Incorporated area	0.72	0.45	0.59	0.63	0.42	0.71	0.65	0.66
Urban area[a]	0.99	0.89	0.91	0.87	0.42	0.88	0.94	0.63
Population	0.43	0.64	0.73	0.60	0.52	0.68	0.86	0.59
Families	0.91	0.91	0.83	0.83	0.32	0.76	0.90	0.20
Housing units	0.89	0.90	0.80	0.80	0.27	0.74	0.87	0.17
Employment	0.91	0.91	0.83	0.82	0.31	0.77	0.89	0.20
Retail firms			0.83					
Retail employment			0.84					
Wholesale firms			0.84					
Wholesale employment			0.85					
Service firms			0.82					
Service employment			0.83					
Commercial firms			0.84					
Commercial employment			0.85					
Manufacturing firms				0.76				
Manufacturing employment				0.73				
Production workers				0.74				
City government employment								0.24
Multiple-family units		0.79						

[a]Equal to sum of land areas for eight classes.

Table 6. Correlation coefficients for LUDA area classes versus census data.

Census Data	LUDA Classification[a] 11	12	13	14	16	17
Incorporated area	0.70	0.64	0.57	0.42	0.62	0.48
Urban area[a]	0.97	0.91	0.86	0.50	0.44	0.62
Population	0.54	0.80	0.82	0.52	0.28	0.86
Families	0.95	0.82	0.79	0.32	0.09	0.40
Housing units	0.93	0.79	0.77	0.27	0.07	0.37
Employment	0.95	0.81	0.78	0.31	0.10	0.40
Retail firms		0.82				
Retail employment		0.84				
Wholesale firms		0.83				
Wholesale employment		0.85				
Service firms		0.81				
Service employment		0.82				
Commercial firms		0.83				
Commercial employment		0.85				
Manufacturing firms			0.71			
Manufacturing employment			0.70			
Production workers			0.71			
City government employment						0.29
Multiple-family units						

[a]Equal to sum of LUDA land area classes.

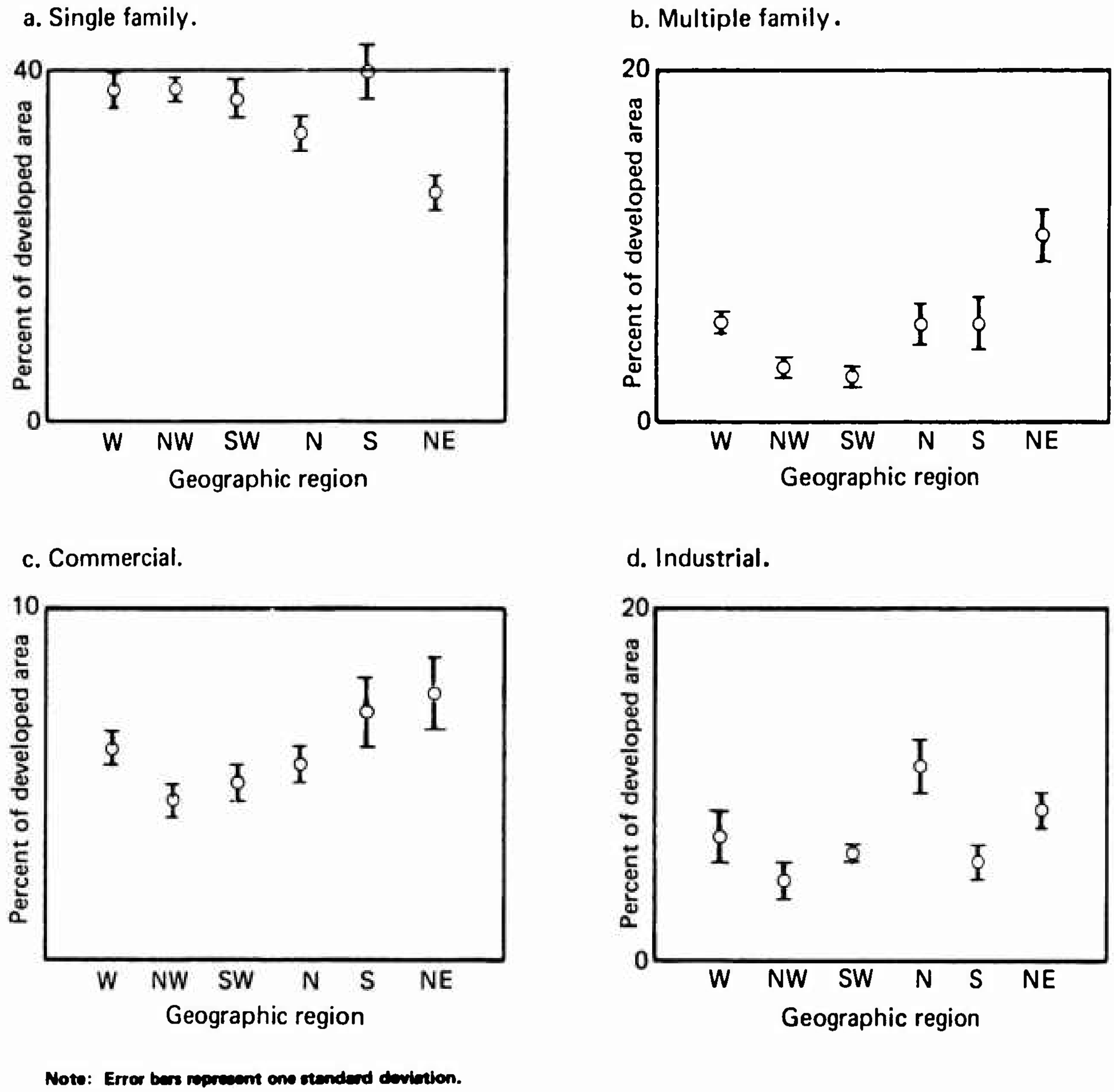
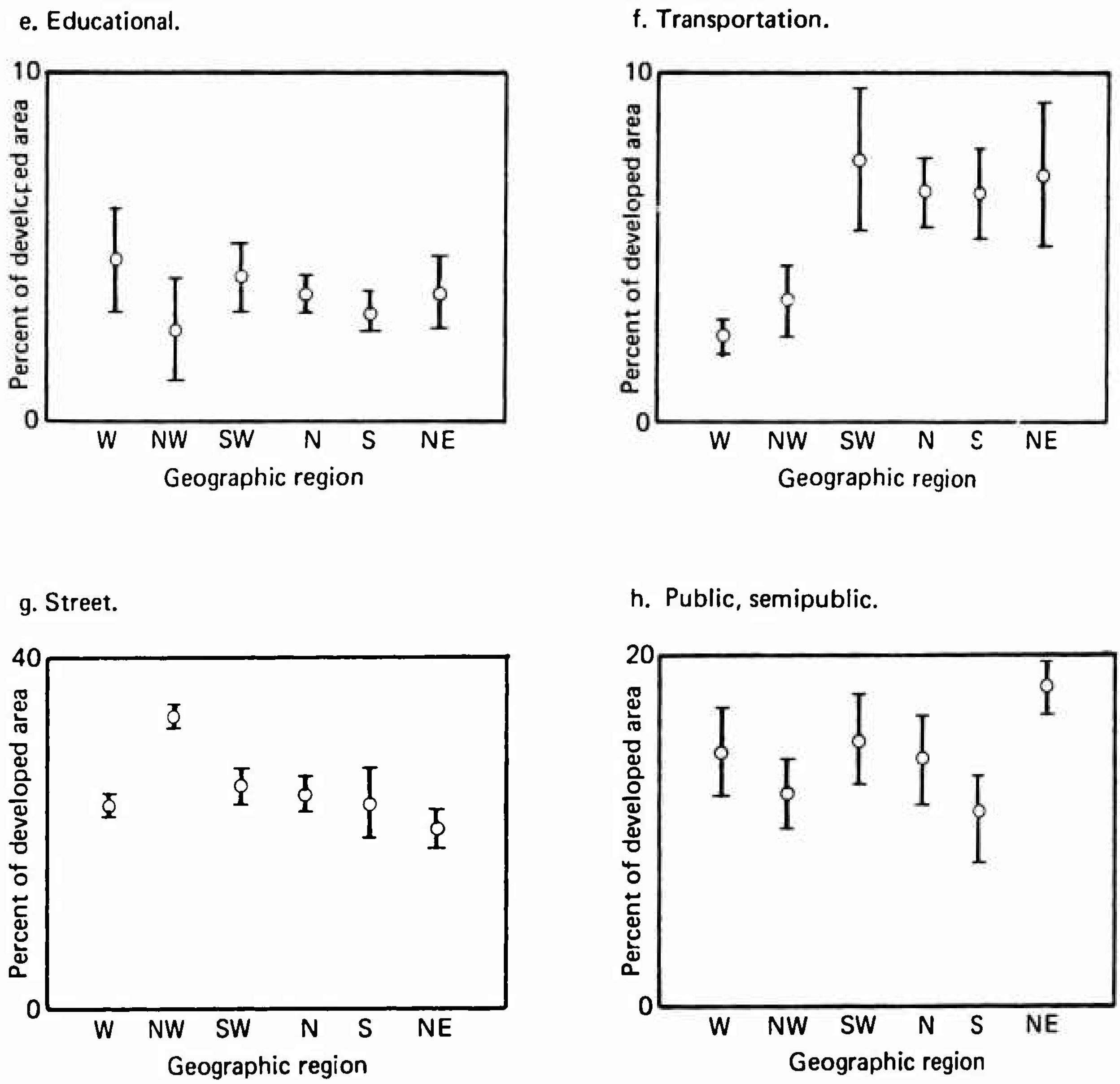
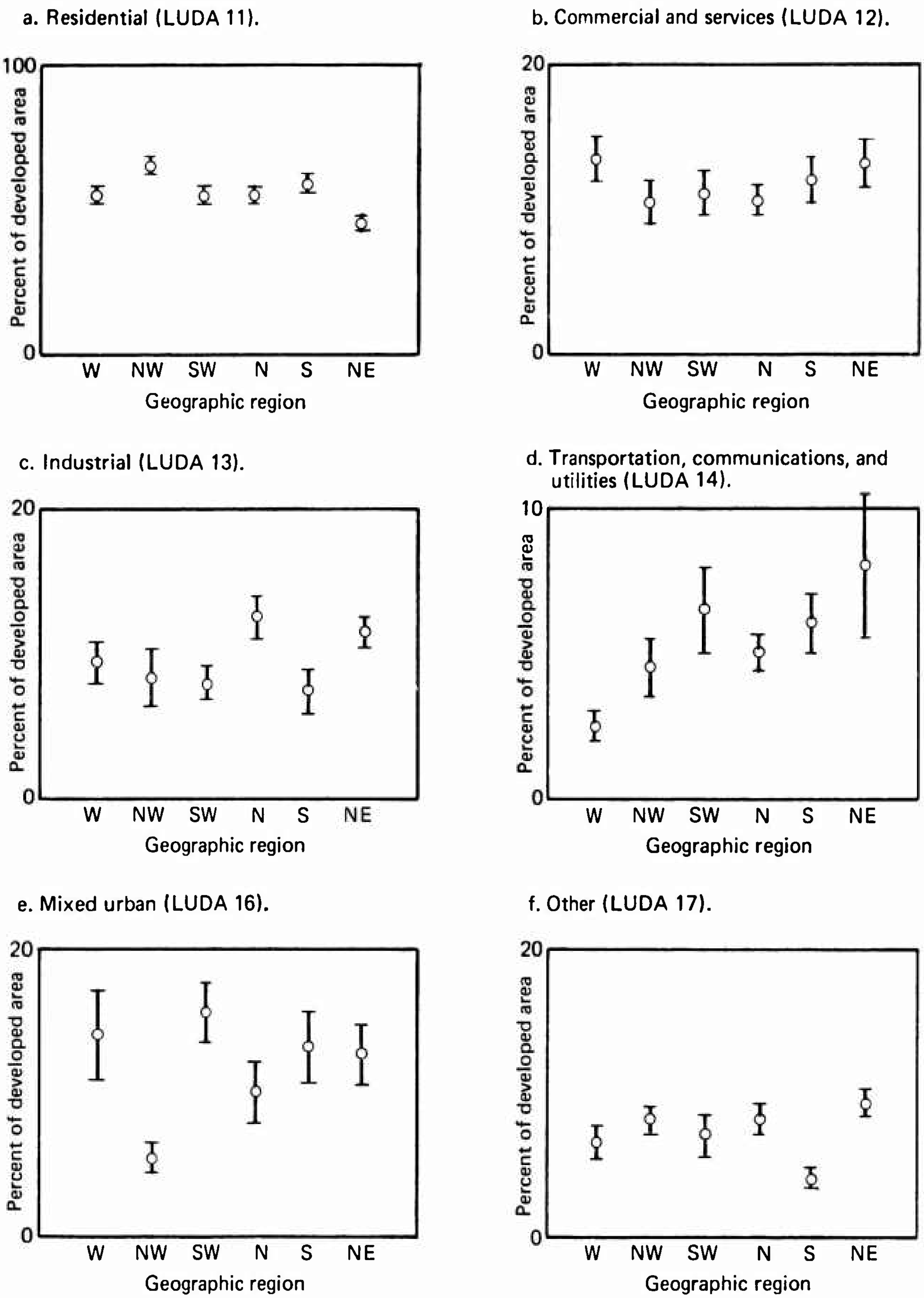


Figure 6. Land use fractional areas for cities in different geographic regions (eight land use classes).



Note: Error bars represent one standard deviation.

Figure 6. Land use fractional areas for cities in different geographic regions (eight land use classes) (Concluded).



Note: Error bars represent one standard deviation.

Figure 7. Land use fractional areas for cities in different geographic regions (LUDA land use classes).

Table 7. Regression coefficients for eight-class area breakdown.

Correlate	Geographic Region W	NW	SW	N	S	NE	All
Single-Family Area							
Incorporated area	0.90	0.98	0.96	0.88	0.73	0.96	0.76
Developed area	1.00	1.00	0.97	0.86	0.90	0.86	0.99
Population	0.98	1.00	0.99	0.85	0.69	0.92	0.43
Families	1.00	1.00	0.95	0.71	0.52	0.30	0.92
Housing units	0.97	1.00	0.94	0.73	0.41	0.29	0.90
Single-family units	0.99	1.00	0.97	0.81	0.74	0.88	0.97
Employment	1.00	1.00	0.95	0.73	0.55	0.22	0.92
Multiple-Family Area							
Incorporated area	0.84	0.99	0.59	0.89	0.07	0.37	0.42
Developed area	0.99	1.00	0.77	0.86	0.86	0.72	0.89
Population	0.96	1.00	0.65	0.93	0.64	0.85	0.79
Families	1.00	1.00	0.87	0.84	0.53	0.81	0.92
Housing units	0.96	1.00	0.88	0.83	0.43	0.82	0.90
Multiple-family units	0.88	1.00	0.75	0.74	0.08	0.72	0.79
Employment	1.00	1.00	0.85	0.83	0.56	0.75	0.92
Commercial Area							
Incorporated area	0.89	0.99	0.89	0.91	0.50	0.89	0.66
Developed area	1.00	1.00	0.94	0.69	0.91	0.86	0.91
Population	0.97	1.00	0.91	0.93	0.54	0.93	0.73
Families	0.99	1.00	0.90	0.55	0.46	0.49	0.83
Housing units	0.95	1.00	0.88	0.56	0.39	0.48	0.80
Employment	0.99	1.00	0.91	0.56	0.48	0.38	0.83
Retail firms	0.99	1.00	0.92	0.53	0.42	0.64	0.83
Retail employment	0.99	1.00	0.91	0.59	0.46	0.71	0.84
Wholesale firms	0.99	1.00	0.91	0.63	0.45	0.28	0.84
Wholesale employment	0.99	1.00	0.92	0.61	0.60	0.23	0.85
Service firms	0.99	1.00	0.87	0.60	0.31	0.36	0.82
Service employment	0.99	1.00	0.91	0.58	0.28	0.21	0.83
Commercial firms	0.99	1.00	0.91	0.58	0.39	0.54	0.84
Commercial employment	0.99	1.00	0.92	0.60	0.47	0.53	0.85
Industrial Area							
Incorporated area	0.91	0.88	0.74	0.70	0.52	0.88	0.70
Developed area	0.99	0.81	0.81	0.54	0.79	0.87	0.87
Population	0.93	0.80	0.79	0.67	0.91	0.82	0.60
Families	0.98	0.79	0.88	0.33	0.87	0.51	0.83
Housing units	0.97	0.78	0.88	0.31	0.80	0.52	0.81
Employment	0.98	0.79	0.85	0.32	0.84	0.41	0.82
Manufacturing firms	0.98	0.87	0.82	0.26	0.45	0.16	0.77
Manufacturing employment	0.97	0.87	0.78	0.36	0.88	0.31	0.74
Production workers	0.98	0.89	0.80	0.35	0.87	0.32	0.75

Table 7. Regression coefficients for eight-class area breakdown (Concluded).

Correlate	Geographic Region W	NW	SW	N	S	NE	All
Transportation Area							
Incorporated area	0.76	-0.37	0.34	0.71	0.78	0.77	0.54
Developed area	0.74	-0.50	0.50	0.71	0.81	0.41	0.42
Population	0.68	-0.52	0.48	0.71	0.59	0.77	0.52
Families	0.73	-0.53	0.63	0.44	0.25	0.75	0.32
Housing units	0.72	-0.54	0.63	0.44	0.14	0.75	0.27
Employment	0.73	-0.52	0.62	0.44	0.20	0.76	0.31
Educational Area							
Incorporated area	0.95	1.00	0.68	0.71	0.84	0.43	0.73
Developed area	0.95	1.00	0.68	0.23	0.90	0.32	0.88
Population	0.79	1.00	0.62	0.80	0.62	0.63	0.69
Families	0.95	1.00	0.58	0.23	0.74	0.62	0.78
Housing units	0.90	1.00	0.55	0.28	0.65	0.63	0.76
Employment	0.95	1.00	0.59	0.28	0.68	0.66	0.78
Street Area							
Incorporated area	0.99	0.99	0.94	0.96	0.83	0.98	0.73
Developed area	0.99	1.00	0.92	0.93	0.77	0.93	0.94
Population	0.97	1.00	0.98	0.96	0.84	1.00	0.86
Families	0.98	1.00	0.94	0.86	0.96	0.75	0.90
Housing units	0.96	1.00	0.93	0.87	0.92	0.74	0.87
Employment	0.98	1.00	0.95	0.87	0.94	0.66	0.89
Semipublic Area							
Incorporated area	0.56	0.98	0.83	0.80	0.12	0.97	0.50
Developed area	0.53	1.00	0.76	0.48	0.72	0.86	0.46
Population	0.20	1.00	0.62	0.71	0.53	0.99	0.73
Families	0.70	1.00	0.66	0.27	0.51	0.37	0.29
Housing units	0.76	1.00	0.63	0.28	0.40	0.35	0.26
Employment	0.70	1.00	0.61	0.27	0.51	0.28	0.28
City government employment	0.68	0.97	0.49	0.28	0.86	0.43	0.29
Sum of Developed Land Use Areas							
Incorporated area	0.99	0.99	0.95	0.97	0.86	0.99	0.94

Table 8. Regression coefficients for LUDA area breakdown.

Correlate	Geographic Region W	NW	SW	N	S	NE	All
Urban Area (No. 1)							
Incorporated area	0.93	1.00	0.93	0.98	0.87	0.98	0.93
Residential Area (No. 11)							
Incorporated area	0.86	0.98	0.95	0.97	0.79	0.99	0.76
Urban area	0.99	1.00	0.95	0.98	0.98	0.95	0.97
Population	0.97	1.00	0.99	0.94	0.65	0.98	0.54
Families	1.00	1.00	0.96	0.84	0.70	0.60	0.95
Housing units	0.97	1.00	0.95	0.85	0.60	0.59	0.93
Employment	1.00	1.00	0.96	0.85	0.72	0.51	0.95
Commercial and Service Area (No. 12)							
Incorporated area	0.91	0.98	0.82	0.91	0.65	0.88	0.70
Urban area	0.99	1.00	0.89	0.96	0.94	0.78	0.91
Population	0.96	1.00	0.80	0.92	0.72	0.96	0.80
Families	0.97	1.00	0.84	0.66	0.63	0.55	0.82
Housing units	0.94	1.00	0.82	0.68	0.56	0.55	0.79
Employment	0.97	1.00	0.85	0.67	0.62	0.47	0.81
Retail firms	0.97	1.00	0.86	0.65	0.53	0.70	0.82
Retail employment	0.97	1.00	0.86	0.69	0.60	0.73	0.84
Wholesale firms	0.97	1.00	0.87	0.75	0.54	0.41	0.83
Wholesale employment	0.98	1.00	0.88	0.74	0.69	0.36	0.85
Service firms	0.97	1.00	0.82	0.72	0.41	0.45	0.81
Service employment	0.97	1.00	0.86	0.71	0.39	0.32	0.82
Commercial firms	0.97	1.00	0.85	0.70	0.50	0.63	0.83
Commercial employment	0.97	1.00	0.87	0.72	0.58	0.62	0.85
Industrial Area (No. 13)							
Incorporated area	0.89	0.83	0.74	0.67	0.37	0.95	0.65
Urban area	0.99	1.00	0.81	0.73	0.69	0.88	0.86
Population	0.94	0.73	0.79	0.65	0.85	0.92	0.82
Families	0.97	0.72	0.87	0.40	0.91	0.57	0.79
Housing units	0.97	0.71	0.87	0.38	0.86	0.57	0.77
Employment	0.97	0.73	0.84	0.38	0.87	0.47	0.78
Manufacturing Firms	0.96	0.81	0.81	0.31	0.44	0.22	0.71
Manufacturing employment	0.96	0.82	0.77	0.40	0.79	0.35	0.70
Production workers	0.97	0.84	0.79	0.40	0.78	0.36	0.71

Table 8. Regression coefficients for LUDA area breakdown (Concluded).

Correlate	Geographic Region W	NW	SW	N	S	NE	All
Transportation, Communication, and Utility Area (No. 14)							
Incorporated area	0.76	-0.37	0.34	0.71	0.78	0.77	0.54
Urban area	0.74	-0.36	0.55	0.84	0.85	0.38	0.50
Population	0.68	-0.52	0.48	0.71	0.59	0.77	0.52
Families	0.73	-0.53	0.63	0.44	0.25	0.75	0.32
Housing units	0.72	-0.54	0.63	0.44	0.14	0.75	0.27
Employment	0.73	-0.52	0.62	0.44	0.20	0.76	0.31
Mixed Urban Area (No. 16)							
Incorporated area	0.52	0.98	0.59	0.70	0.06	0.95	0.46
Population	0.15	1.00	0.60	0.58	0.50	0.93	0.44
Families	0.56	1.00	0.60	0.07	0.37	0.44	0.22
Housing units	0.59	1.00	0.58	0.08	0.27	0.42	0.19
Employment	0.56	1.00	0.57	0.07	0.37	0.37	0.21
Open and Other Area (No. 17)							
Incorporated area	0.85	1.00	0.84	0.91	0.36	0.98	0.48
Urban area	0.63	1.00	0.74	0.93	0.73	0.65	0.62
Population	0.61	1.00	0.64	0.92	0.74	1.00	0.87
Families	0.86	1.00	0.67	0.91	0.86	0.39	0.42
Housing units	0.90	1.00	0.64	0.91	0.81	0.40	0.39
Employment	0.86	1.00	0.62	0.90	0.78	0.36	0.41
City government employment	0.85	1.00	0.48	0.90	0.69	0.33	0.30

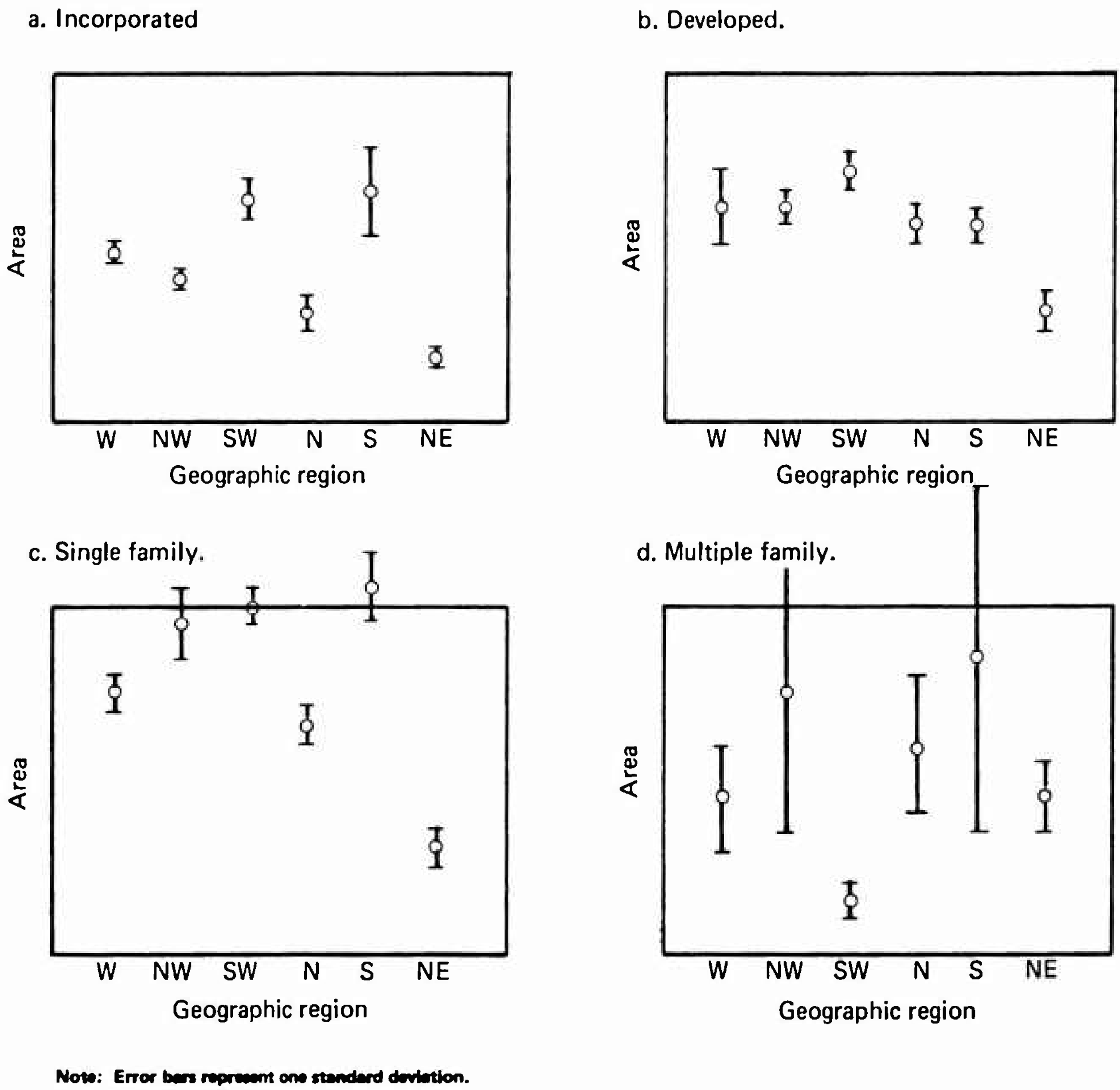
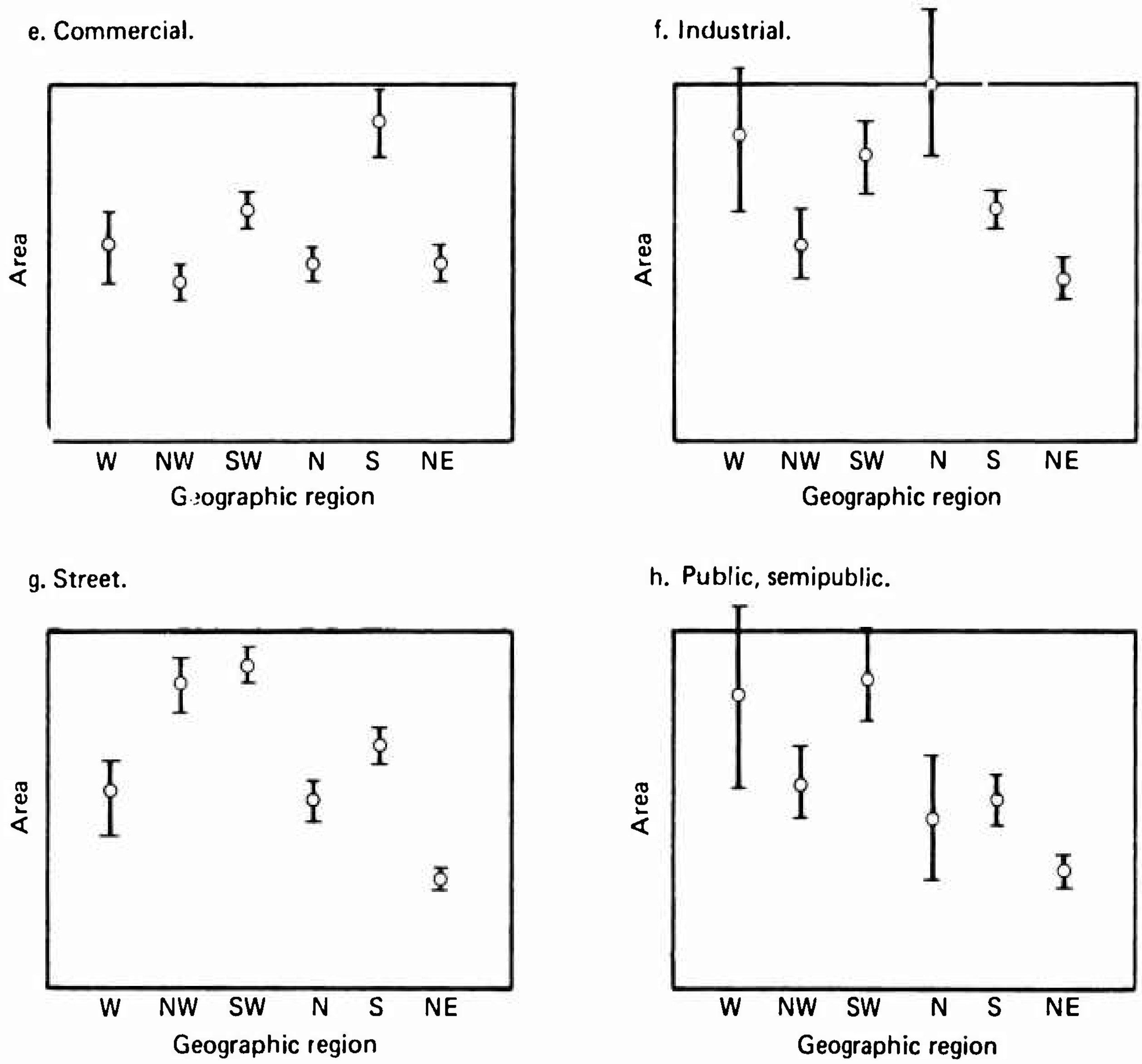


Figure 8. Per capita land use for cities in classification groups.



Note: Error bars represent one standard deviation.

Figure 8. Per capita land use for cities in classification groups (Concluded).

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